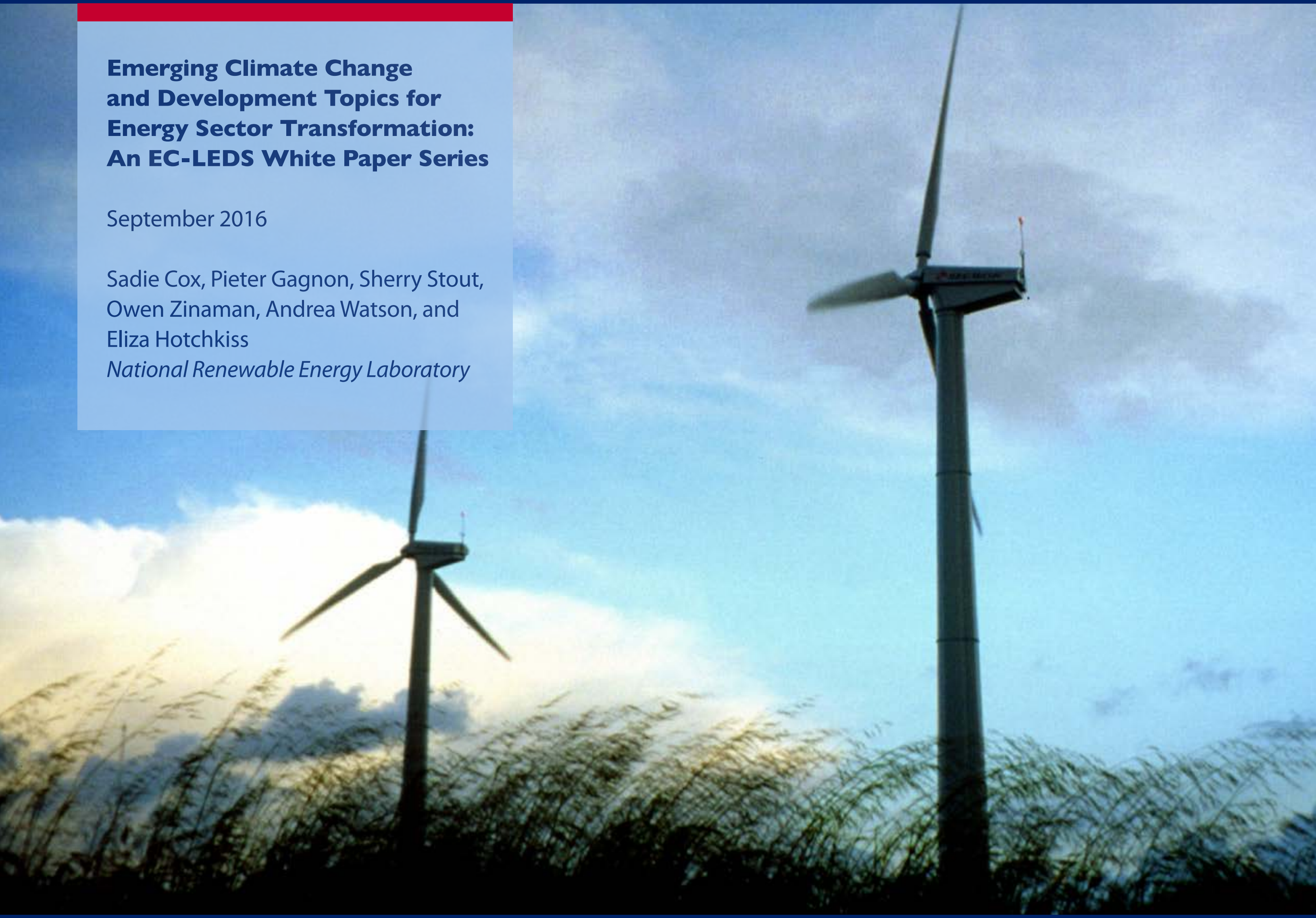
DISTRIBUTED GENERATION TO SUPPORT DEVELOPMENT-FOCUSED CLIMATE ACTION



Emerging Climate Change and Development Topics for Energy Sector Transformation: An EC-LEDS White Paper Series

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EC-LEDS
ENHANCING CAPACITY FOR LOW EMISSION DEVELOPMENT STRATEGIES

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INTRODUCTION

The international community is collectively working to achieve interlinked sustainable development goals that will support a low-emission, climate-resilient future. 196 countries signed the Paris Agreement in 2015, committing to keeping global temperature rise below 2 degrees Celsius while also supporting critical adaptation efforts (UNFCCC 2015). To meet growing electricity demand,[1] many countries have prioritized scaling up renewable electricity generation as a primary pathway to achieving these outcomes.

Distributed generation (DG) can play a critical role in supporting achievement of development-focused climate goals articulated in the Paris Agreement and within Nationally Determined Contributions, low emission development strategies (LEDS), and other national and subnational climate plans. DG's role is particularly relevant to those countries where demand growth is high, loads are geographically dispersed, and new energy infrastructure is being built or planned. Further, as decentralized generation is being increasingly deployed as a valuable component within broader generation portfolios, the global community is gaining insights and identifying good practices to effectively harness this technology to achieve a wide range of policy goals and social services.

This paper explores the role of DG, with a high renewable energy contribution, in supporting low emission climate-resilient development. The paper presents potential impacts on development (via energy access), greenhouse gas (GHG) emission mitigation, and climate resilience directly associated with DG, as well as specific actions that may enhance or increase the likelihood of climate and development benefits. This paper also seeks to provide practical and timely insights to support DG policymaking and planning within the context of common climate and development goals as the DG landscape rapidly evolves globally. Country-specific DG policy and program examples, as well as analytical tools that can inform efforts internationally, are also highlighted throughout the paper.

[1]Global electricity consumption is forecasted to increase from 23,000 TWh in 2013 to 39,000 TWh in 2040, a CAAGR of 2.0%. Much of the increases will be in developing countries, such as India, which is forecasted to see a CAAGR of 4.7% over that same timeframe (IEA 2015a).

DISTRIBUTED GENERATION OVERVIEW: DEFINITION AND TRENDS

Distributed generation is the production of electricity near its point of use. This is a complementary alternative to the production of electricity in large centralized plants and subsequent transmission (often over long distances) to the consumer. Whereas centralized production has traditionally been the most cost-effective and attractive investment option for providing modern energy access, declining costs and maturing technologies are shifting the electricity provision paradigm toward a future where DG can play an important role within the broader power sector portfolio.

Box 1. Defining Microgrid and Minigrid

The terms microgrid and minigrid are often used interchangeably. A microgrid consists of DG and interconnected loads within a clearly defined electrical boundary that acts as a single controllable entity with respect to the grid. Microgrids can either be connected to the grid or apart from it. If connected to the grid, microgrids can disconnect to enable island-mode operation Ton and Smith 2012. A subset of microgrids, minigrids are permanently islanded and are not designed to interconnect to the larger grid. Minigrids may also be referred to as rural energy power systems for islanded power systems.

DG is highly scalable, can be deployed rapidly, and does not rely on difficult to finance transmission infrastructure. This positions DG to be a critical means to support many nations' development goals. For example, increasing energy access is an important development goal in a number of countries and often can be supported most cost-effectively using DG technologies. When DG capacity is drawn from renewable resources, there can be additional benefits related to climate resilience and GHG emission mitigation. Further, households or institutions can directly procure distributed generation capacity for the electricity system allowing their own preferences in the carbon intensity and resilience of electricity procurement to be expressed.

Centralized approaches to electricity generation planning and investment are established components of a utility's capacity planning processes. Within these processes, it is increasingly important that DG technologies are also evaluated so that opportunities where distributed approaches would align with broader development and climate goals are recognized. This paper focuses on distributed solutions to energy issues—however, it should be noted that in most cases DG serves as a complement to the grid and not necessarily a replacement of central generation and distribution. Additionally, DG interconnection to the larger grid has both technical and financial complexities for consideration. Appropriate codes, standards, and compensation mechanisms can be adopted to ensure the maximum grid benefits of DG (Linvill et al. 2013; Bird et al. 2013). Strategies to do so are widely characterized in the literature and are not the focus of this paper.[2]

Technologies and architectures for DG systems vary widely, but they can be broadly categorized as being grid-connected or off-grid. Two common DG technologies, which are a primary focus of this paper, are microgrids and minigrids. For the purposes of this paper, definitions of microgrids and minigrids are presented in Box 1. Sections below present technical options and key trends related to grid-connected and off-grid renewable-based DG markets globally.

[2] See, for example, Linvill et al. (2013) and Bird et al. (2013).

GRID-CONNECTED DISTRIBUTED GENERATION

Grid-connected DG consists of any generators that primarily serve local loads, but are still connected to the centralized grid. Integration architectures of these generators can range from simple household energy systems to complex microgrids with sizes ranging from several kilowatts (kW) up to many megawatts (MW), but they are characteristically interconnected to the central grid at a distribution voltage.[3] Although many kinds of distributed renewable generation can be deployed—including wind, micro-hydropower, and biomass—the most common DG energy system is a solar photovoltaic (PV) array. The uncontrolled diurnal variation of PV generation means that these systems typically supply only a portion of the electricity consumed by a household or commercial facility, where the critical service of actually matching generation to demand is provided either by on-site thermal components—such as diesel generators—or by the local utility via the grid.

The impact of these systems can be mixed. Their benefits to utilities include being a means to lower GHG emissions and, in some cases, may allow them to defer expensive generation or distribution infrastructure investments. Additionally, implementing power generation at or close to where it is used also reduces electrical losses associated with the transmission and distribution (T&D) system. With proper supporting technologies and policies, rooftop PV, distributed wind, or micro-hydro can also provide a community with a source of electricity for basic needs during disasters. When deployed in large numbers, however, DG systems with significant amounts of renewable generation can also raise integration challenges. For the distribution system, these challenges include unplanned voltage variations and power flows in distributions systems originally designed for one-way power flow and the need for more complicated configurations of circuit breakers and other protection equipment (Palmintier et al 2016). For the broader power system, the variability of renewable generation can complicate the procurement and dispatch of other generators and increase their ramping requirements, among other operational challenges (Denholm et al. 2016).[4] Careful planning with a mixture of different DG technologies or the use of enabling technologies, such as energy storage and smart inverters, can help mitigate some of these challenges. The Greening the Grid website, highlighted in Box 2, provides guidance and resources to support renewable energy grid integration, including DG. With a more specific focus on DG, the Distributed Generation Interconnection Collaborative, highlighted in Box 3, supports sharing of solutions to address key DG interconnection challenges.

Microgrids are more complex grid integrated approaches that offer additional development benefits. For example microgrids that incorporate several generation and energy storage technologies, such as PV, batteries, and diesel, can offer improved resilience via fuel diversity and storage. They also can be configured to allow for islanding, therefore preventing disruption of commercial activities when the main grid goes down. However, systems that incorporate diesel generation will have associated GHG emissions as well as potentially high and often volatile fuel costs. The appropriate mix of grid-connected DG technologies to meet climate and development goals will be unique to the specific settings and circumstances within countries and local jurisdictions.

Box 2. Greening the Grid

The U.S. Agency for International Development (USAID) partnered with the National Renewable Energy Laboratory (NREL) to develop the Greening the Grid initiative, which provides guidance, webinars, and a free Ask an Expert service to support renewable energy grid integration. In particular, the Greening the Grid website provides example interventions, case studies, and policy examples to support distributed renewable integration. For additional information, please see greeningthegrid.org/integration-topics/distributed-generation and greeningthegrid.org.

[3]Distribution voltage is typically between 4 and 35 kilovolts (kV). [4]Ramping is the change in the quantity of power produced by a generator. The need to rapidly ramp central generators can be increased by the unforeseen variation in the output of wind or solar generation. This is most prominent near sunset, as solar generation is rapidly decreasing and demand by the residential sector is often simultaneously increasing.

Due primarily to rapidly declining prices, grid-connected PV and wind technologies have both become cost-competitive with other generation sources in many locations in terms of the levelized cost of energy.[5,6] However, grid-connected DG markets are still nascent in a number of contexts, especially in developing countries. Various policies can be established to support grid-connected DG, including robust interconnection standards and innovative financing mechanisms such as revolving loan funds and on-bill financing schemes.[7] Additionally, a unique set of challenges and opportunities is associated with establishing compensation mechanisms for DG. This will not be discussed in this report; however, Linvill et al. (2013) and Bird et al. (2013) review many of these issues in detail. Higher-level strategies and approaches to integrate DG into centralized electricity planning and policymaking are explored in sections below.

OFF-GRID DISTRIBUTED GENERATION

In rural and remote areas, centralized approaches to electricity expansion—in which utilities reach non-electrified communities by building transmission lines—can be cost-prohibitive on a dollar per kilowatt-hour basis, difficult to finance, and slow to build. In contrast, decentralized, off-grid DG approaches can offer a more cost-effective and quick-to-deploy alternative solution. Off-grid DG can include generators used in stand-alone household energy systems, energy sources for small low-voltage direct current (DC) minigrid systems, or as the energy supply for medium-voltage alternating current (AC) minigrids. The appropriate system design will be highly dependent on unique local circumstances (e.g., usage characteristics of customers and quality of various energy resources such as biomass, solar, or wind) and overarching policy goals.

Over the past decade, low-voltage DC products have proliferated, often as the first step on the ladder of energy access. They typically provide just several watts of power to homes for basic services like lighting and cell phone charging. As of 2015, an estimated 100 companies specialized in solar lanterns and solar home system kits (BNEF and Lighting Global 2016). The majority of the more than 20 million units sold were portable lights with less than 10 watts of power; however, it is anticipated that cost reductions and consumer demand will drive the introduction of additional products into the marketplace. Recent forecasts suggest that 15 million off-grid households will use solar home systems to power a TV by 2020 (BNEF and Lighting Global 2016). The most critical factor driving the adoption of low-powered systems is the drastic decline in the price of PV technologies.

Medium-voltage AC minigrids typically leverage multiple technology types as electricity sources, such as PV, wind, biomass, and diesel. Critically, these medium-powered AC grids can support energy-intensive income-generating activities that low-powered DC grids cannot (Mapako and Prasad 2007). Compared to DC grids, however, there are greater technical and financing challenges associated with medium-voltage systems. These challenges have thus far limited private sector participation in this form of electrification. In particular, although electrification with minigrids has been shown to cost less than centralized grid expansion in certain locations, the actual return on the project investments vary significantly and are often insufficient to meet the rates of return required to motivate the private sector. A small number of cases—often fueled by inexpensive sources of local biofuel or hydropower, or based around a large "anchor" customer—have proven to be financially viable, but many rural

Box 3. Distributed Generation Interconnection Collaborative

The Distributed Generation Interconnection Collaborative (DGIC) is a collaborative initiative that brings together the Electric Power Research Institute (EPRI), NREL, Smart Electric Power Alliance (SEPA), and Western Area Power Administration (WAPA) to support peer learning on distributed PV interconnection issues. DGIC was created to foster knowledge sharing to maximize DG complements to the grid while finding solutions to DG interconnection challenges. Its quarterly meetings and webinars present research, case studies, and discussions on DG interconnection and planning topics. For additional information, please see http://www.nrel.gov/tech_deployment/dgic.html

[5]The levelized cost of energy (LCOE) is the present value of a project's cost of generation, often expressed in cents per kWh, where both the project cash flow as well as energy generation is discounted using standard financial equations. This metric only considers the cost of energy generated by a system, and not other important aspects such as whether the energy can be dispatched. Therefore, while LCOE is a useful metric for flexible grids where non-dispatchable resources can be easily incorporated into the portfolio, and for tracking a technology's cost over time, it contains insufficient information to be used alone to fully compare generation options.
[6]See Orell and Foster (2015) for an updated report on the state of distributed wind technologies. [7]These policies and support mechanisms are well-characterized in the literature and not the subject of this report.

sites do not benefit from the same opportunities. Challenges related to uncertain load forecasts and renewable resources, the potential for failure due to inadequate maintenance or poor quality equipment, limited economies of scale and access to capital, and lack of trained personnel to operate and maintain systems have all hindered deployment thus far (Schmidt et al. 2013). Further, low-powered DC systems often replace kerosene purchases and are able to capture that existing cash flow, but in many of the sites that would benefit from a medium-powered system, there are no established revenue streams large enough for the system to capture and return a profit. In addition to these characteristics, there is a limited understanding of the technology, market, and investment potential within the financial community all represent barriers to the mobilization of capital. Actors around the world are working to address these challenges, and the sections below highlight various proposals to address these barriers and support private investment in medium-sized DG systems.

Customer dissatisfaction can be another challenge to off-grid DG deployment. This has occurred in some cases where either there was an expectation of grid-level service or grid-level service was desired after a period of time. Depending on the design of the off-grid system, the difference in performance can include either the intermittency of service or limits to the types of devices that can be powered by the minigrid, and the dissatisfaction itself often relates to provision of incomplete or inaccurate information about the capabilities of off-grid DG systems (Schäfer et al. 2011). To address this and other key challenges highlighted above, information and best practices are being shared through efforts such as the Quality Assurance Framework for Minigrids, highlighted in Box 4. Further, minigrid system research and development continues to improve minigrid performance and reduce maintenance needs (EUEI 2014).

Although challenges to off-grid DG exist, the market is expanding rapidly and actors are working to address barriers. Through actions described in this paper, off-grid DG is providing a critical solution to support energy access and broader development and climate goals, highlighted in the next section.

Box 4. Quality Assurance Framework for Minigrids

Acknowledging the current challenges of providing reliable power through financially viable minigrids, the Global Lighting and Energy Access Partnership (Global LEAP) and the NREL developed a quality assurance framework for isolated minigrids. The framework includes two key components to support minigrid investment and deployment:

- Defining the appropriate "level of service" (i.e., power quality, reliability, and availability) to be provided by the minigrid in relation to unique local circumstances
- Providing a common accountability and reporting framework to validate power delivery and communicate results to stakeholders.

Further, the approach seeks to characterize investment frameworks to support the financial community in understanding minigrid investments in a standardized manner. This could also allow projects with similar sizes, technologies, services provided, and risk profiles to be aggregated under broader investment portfolios to enable finance mobilization.

The Minigrid Quality Assurance Framework is expected to play a key role in mobilizing investment for minigrids in developing markets.

Source: Clean Energy Ministerial (n.d.)

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DISTRIBUTED GENERATION AND LOW EMISSION CLIMATE-RESILIENT DEVELOPMENT

The next three sections explore the role of renewable DG in supporting interlinked development, GHG emission mitigation, and climate resiliency goals unique to various countries and jurisdictions. By enabling positive impacts in each of these areas, DG can serve as an important technology within the broader portfolio of renewable electricity options to support low-emission climate-resilient development globally.

DISTRIBUTED GENERATION AND DEVELOPMENT THROUGH ENERGY ACCESS

The United Nations' Sustainable Development Goals create a direct link between elimination of extreme poverty and protection of the environment at the global level. In particular, Goal #7 sets a target of universal energy access by 2030 through deployment of reliable, clean, modern, and affordable energy technologies. Achieving this goal will require bringing electricity to more than 1.2 billion people who, as of 2015, did not have access to electricity. Eighty percent of these 1.2 billion people live in remote areas of Asia and sub-Saharan Africa (IEA 2016). Lack of access to electricity can have significant negative implications for income generation opportunities, health, education, and gender equality, as well as other areas of social and economic development.

Common electricity technology options to support energy access include household energy systems, minigrids,[8] and central grid connection (depicted in Figure 1). A mixture of DG and central electricity provision has been shown to typically be the most cost-effective means of achieving universal electrification (Levin and Thomas 2012). Additionally, the typically short amount of time required to deploy even large amounts of DG make this an attractive means to reach underserved people. Under traditional

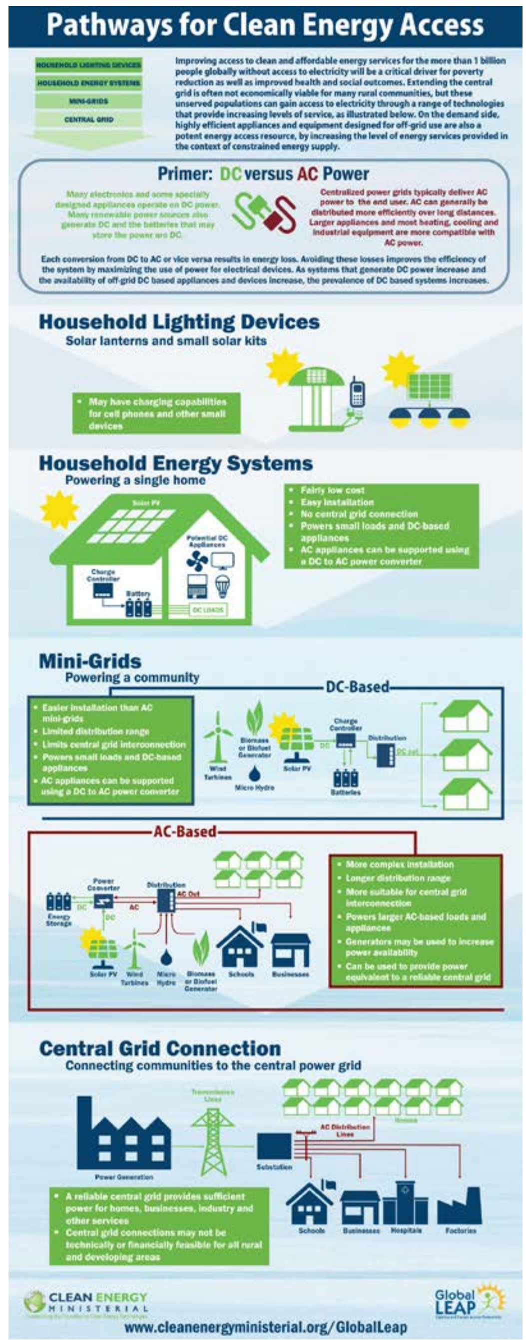

Figure 1. Common electricity options to support energy access

[8]Please note that this section refers primarily to minigrids as they are used more commonly than microgrids in rural settings to support rural electrification and energy access goals. However, microgrids can also be an appropriate option in some locations, depending on unique circumstances, such as proximity to the central grid.

electricity provision models, power is provided to users primarily through the central grid. Therefore, access to electricity was tied to cost of grid extension (Odarno et al. 2015a). In areas of sufficient population density, an approach built around centralized generation is often the most cost-effective way to distribute power. However, in areas with lower population density and lower power demand, a centralized approach can be cost prohibitive. Importantly, the significant cost of extending transmission and the losses associated with long transmission networks to rural areas located far from the central grid often make centralized solutions uneconomical. Furthermore, lengthy planning phases have historically made capital-intensive grid extension a slow process. In these cases, off-grid DG approaches across the range of the options shown in Figure 1 can offer a more cost-effective and timely alternative.

Key considerations to inform the choice of electricity options to expand energy access include:

- Distance of community from the central grid, population density, and power demand
- Quality of local renewable resources, such as solar and wind
- Potential environmental impacts of installing T&D lines from a central grid (e.g., removal of forested areas)
- Costs and price volatility of traditional fuels (e.g., diesel and kerosene) used for generators and other services (e.g., lighting) and the cost of transportation and storage of the fuels in remote areas
- Costs of different DG and control technologies that make up the minigrid system
- Potential workforce development requirements to enable a community to operate and maintain systems
- Alignment with other national priorities such as climate change mitigation and resilience.

Based on analysis of the considerations above, renewable-based DG can provide an important option for electricity provision to support energy access in various communities around the world. In these cases, DG can facilitate the realization of multiple development benefits highlighted in Table 1. For a specific example, Box 5 highlights agricultural income generation opportunities supported by minigrids with a high renewable energy contribution implemented through the Powering Agriculture Initiative.

Box 5. Powering Agriculture Initiative

Through the Powering Agriculture Initiative, Husk Power Systems and development partners in Nigeria and Ghana are developing biomass gasification and solar PV hybrid minigrids to reliably power off-grid agriculture communities. These battery-free systems provide clean power to a variety of agriculture loads and household appliances, 24 hours a day. Support from the Powering Agriculture Initiative has allowed for the expansion of this model that was originally piloted in India and Tanzania, where 70 minigrids were deployed to provide power to over 20,000 homes.

Source: Powering Agriculture (2016)

While important development benefits of DG are highlighted above, it is also important to consider potential negative impacts (e.g., land use tradeoffs associated with biomass DG). Further, ensuring that benefits are realized across communities can be crucial in avoiding potential social conflicts and equity issues associated with unequal electricity provision. Multi-criteria impact assessment can be used to evaluate economic, social,

TABLE 1. POTENTIAL DEVELOPMENT BENEFITS ASSOCIATED WITH DG-DRIVEN ENERGY ACCESS

Economic development	Enterprise and business development (e.g., battery charging, mobile phone rental, business operations using welding, mills, pumps, and power tools, and other traditional businesses) and improvement (e.g., extended business hours and connection to the global market). Financial benefit through decreased expenditures on energy services such as kerosene, diesel, dry cell batteries, and candles. Increased time for other productive purposes (e.g., less time spent collecting fuel resources or commuting for battery charge services).
Health	Reduction of use of fuel-based lighting or indoor fires resulting in improved indoor air quality/reduced respiratory illness and fewer fire-related injuries. Improved health facilities and services (e.g., provision of basic medical procedures and refrigeration of vaccines and medicines). Improved water sanitation through use of electricity for water treatment, sanitation, and distribution. Higher food quality and improved health through refrigeration.
Education	Improved study environments through provision of lighting services. Expanded learning opportunities through access to computers and other technologies. Expanded availability of advanced communications including access to advanced learning.
Gender equality	Increased availability of time to allow for education of girls, support women's productive endeavors, and improve quality of life overall (e.g., women and girls can spend less time collecting fuel resources and improve efficiency of cooking processes through use of electric appliances). Improved health for women and girls who spend significantly more time inside the home and are thus more affected by indoor air pollution and associated respiratory illnesses. Further, maternal mortality rates can be significantly reduced through electrification of rural clinics. Improved personal safety through community lighting.

Adapted from Walters et al. (2015)

and environmental impacts of DG and other electricity provision options. Under a multi-criteria impact assessment process, policymakers and practitioners can evaluate and prioritize electricity options in relation to key criteria that align with national or local goals such as reducing GHG emissions, expanding energy access, or supporting climate resilience. Pursuing this type of assessment early in a rural electrification planning process and with input from diverse stakeholders can allow for identification of possible challenges and increased support for actions with potential positive impacts (Odarno et al. 2015b).

Policymakers and other stakeholders can consider several actions to support energy access and related development goals through DG deployment. Key actions are described below. As highlighted in Box 6, the government of India has worked to incorporate some of these key actions with rural electrification efforts.

INFORMATION PROVISION

Governments can support provision of transparent information on central grid expansion plans to send a clear signal on rural electrification opportunities to private developers (Walters et al. 2015). This information can also help the private sector consider clusters of villages or communities for minigrid development that might allow for streamlined management across the minigrids and reduced costs related to travel and maintenance networks. The private sector may also use this information to identify anchor customers (e.g., medium-sized businesses such as agricultural companies or telecommunication stations) to support steady and dependable income (EUEI 2014).

COMMUNITY-BASED LEADERSHIP

Minigrids owned and operated at the community level can provide an inclusive and consumer-led model to support energy access. Policymakers can support community minigrids by connecting communities with reliable minigrid developers and, in some cases, providing direct financial support for minigrid development through grants and other mechanisms. Further, the development of sustainable community minigrid business models (e.g., tariff design for adequate and equitable revenue collection) and support for training of local technicians to ensure operation and maintenance of the system (EUEI 2014).

Because of the risk associated with the failure of equipment in community-based power systems, the development of multi-community risk pools, utility management training, and development of capital reserve funds are critical to long term sustainability. A summary of best practices for the operation of rural microgrids, obtained through a critical review of seven case studies, can be found at Schnitzer et al. 2014.

Box 6. Rural Electrification in India

In 2016, according to the World Bank, 21.3% of India's population, or more than 260 million people, lacked access to electricity, underscoring the challenge of electrifying rural communities.

The government of India launched a rural electrification policy in 2005 with the stated "goal of electrifying all un-electrified villages/un-electrified hamlets and providing access to electricity to all households in next five years." This policy also clearly articulated areas for off-grid DG development (rather than central grid expansion) to support rural electrification.

Recently, India's Ministry of Power has updated its rural electrification program to include expanded support for centralized grid expansion by covering project costs through grants and loans.

As the government of India works to supply electricity to rural communities through grid expansion, opportunities have emerged for the donor community and the private sector to bridge the gap through DG. For example, through USAID's Development Innovation Ventures program, USAID has partnered with private company Mera Gao Power to test and scale up microgrids to provide low cost power to off-grid villages in India.

India is incorporating several good practices to support expanded rural electrification, both on-grid and off-grid. Importantly, the government has utilized a quality assurance methodology for implementation of DG systems, clearly defined the use of microgrids as either medium or long-term solutions, and provided transparent planning information to support private investment.

As a notable recent development, in June 2016, the United States government and the government of India announced the U.S.- India Catalytic Solar Finance Program which will provide up to $40 million USD from US foundations and the government of India to support solar rural electrification. The initiative also seeks to mobilize $1billion USD in private capital to support solar deployment.

Sources: India Ministry of Power (2016); World Bank (2016); USAID (2015); Odarno et al. (2015b); The White House (2016).

Figure 2. USAID's partnership with Mera Gao Power supports microgrid testing and scale-up to provide low-cost power to off-grid villages in India.
Source: USAID (2015)

INCENTIVE DESIGN AND IMPLEMENTATION

To encourage private sector investment and operation of minigrids through improved economic returns, several incentives can be considered including loan guarantees, results-based financing, grants, and other subsidies (e.g., microfinance program subsidies) (EUEI 2014). To align with broader development goals, governments can also consider subsidizing tariffs for electricity from renewable-based minigrids in poor communities or poor consumers.[9] Governments can also design "buy-back" or leasing programs for smaller scale solar home systems and minigrids in the event that the central grid is extended to a rural area in the future.[10] This approach can support both private sector and direct consumer investment in DG technologies in rural areas.

PUBLIC-PRIVATE PARTNERSHIP

Public-private partnerships can allow a government to directly support rural electrification through collaboration that leverages private sector skills and expertise. Under one approach, governments can fund and own minigrids while partnering with private sector entities to develop, operate and maintain the systems through contracts and concessions. These partners are often called energy service companies (ESCOs). Power purchase agreements can also be designed to allocate responsibility for electricity generation and distribution across different entities within the public and private sectors.

PUBLIC UTILITY PARTNERSHIP

To support rural electrification goals, public funding can also be provided to utilities to support minigrid development and operation in rural areas. Utilities employ distribution engineers that can serve as technical experts in implementing DG projects to support energy access. Given that utilities traditionally focus on central grid operations, additional human capacity will be needed within the utility to manage a minigrid portfolio.

In all of these models, the implementation of a regulatory or oversight framework such as is common in grid-connected utility organizations, can ensure long-term sustainability of the individual minigrid projects (Tenenbaum et al. 2014).

As presented above, DG and supportive actions can play an important role in realizing the global Sustainable Development Goals at the national and local levels. The next sections will build on this information to describe the role of DG in supporting interlinked GHG emission mitigation and climate resilience goals.

DISTRIBUTED GENERATION AND AVOIDED GHG EMISSIONS

In addition to its role in facilitating economic and social development through expanded energy access, renewable-based DG can also support key emission reduction goals articulated in Nationally Determined Contributions and LEDS.

The characterization of avoided emissions associated with DG deployment is markedly different for grid-connected and off-grid renewable-based DG. In the case of grid-connected DG, the effect of the local capacity on total electricity consumption is not straightforward and varies by situation. For example, in some instances DG may not displace centrally produced electricity, but instead simply increase the total amount of electricity consumed.

[9]It should be noted that fuel subsidies for diesel-based minigrids are a common barrier to hybrid and renewable-based minigrid development. [10]To maximize the value of a bought-back system, deployment in areas with these programs should be compatible with the central grid through codes and equipment standards. For more information see chapter 5 of Zinaman et al. (2015).

However, in other cases, a given kilowatt-hour of electrical generation from grid-connected DG may displace a kilowatt-hour of centrally produced electricity.

To begin to shed light on this topic, Figure 3 shows the avoided CO_2 per kilowatt of PV capacity as a function of the average carbon intensity of the local grid for the year 2013 for 84 countries.[11] The scatter is a result of the varying solar resource quality among the nations.[12]

Figure 3 shows that the avoided CO_2 per installed kilowatt of distributed PV capacity can vary from almost 1.8 tons/kW/year to nearly 0 tons/kW/year. The trend demonstrates that PV's avoided emissions from offset fuel combustion is more strongly driven by the local grid carbon intensity than the quality of the local solar resource. For example, Ethiopia currently generates the majority of its electricity from hydropower, and therefore displacing a kilowatt-hour of centrally provided electricity with renewable DG electricity avoids essentially zero emissions.

Table 2 gives a simple characterization of the potential avoided emissions if a portion of new electric generation is sourced from renewable DG, with some additional information about the capacity required if that energy is to come from grid-connected DG PV. The analysis considers a hypothetical scenario where each region increased its total annual electricity generation by 5%, and 10% of that increase came from DG PV.

Critically, both of these simple illustrations estimate the potential to avoid emissions by comparing DG PV buildout against a case where the electricity produced by the PV system would have otherwise been produced by central grid capacity at current carbon intensity. In practice, renewable technologies can be used for centralized capacity expansion as well, and therefore similar reductions in emissions can often be achieved by deploying renewable technology in a centralized architecture.[13]

Whereas grid-connected DG is often characterized as generating electricity locally to displace what would have otherwise been provided through the grid, off-grid DG is entirely separate from the centralized generation and distribution of electricity. As a result, a discussion of avoided emissions from renewable technologies in off-grid DG systems is different from grid-connected DG. While grid-connected DG can be assumed to offset emissions at the emissions intensity rate of the local grid, minigrids are often proposed in places where there is little to no previous electricity consumption.

Separate from the potential for grid-connected DG to avoid emissions, there is an opportunity in hybridizing or outright replacing fossil-fueled generators on island minigrids throughout the world. There are 2056 islands worldwide that are powered by minigrids, with an estimated total annual electricity consumption of 52.7 TWh (Blechinger et al. 2014) in addition to an unrecorded number of isolated diesel power stations likely to reach into

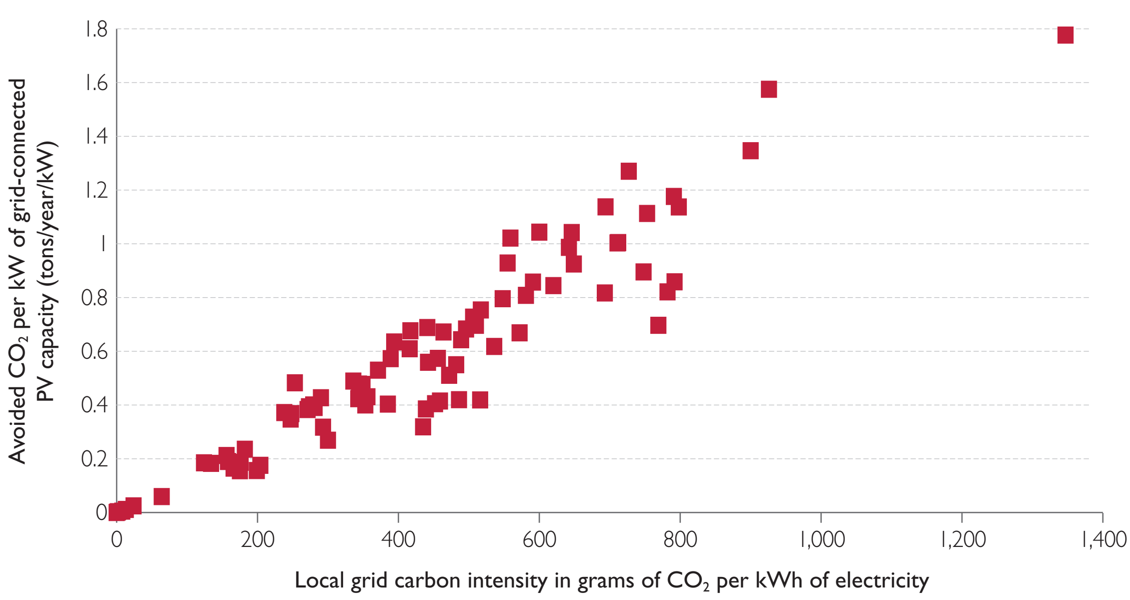

Figure 3. Avoided emissions per installed kilowatt of distributed PV capacity

[11]This is a simple illustrative plot only to demonstrate the relative strength of local grid carbon intensity and solar resource on avoided fuel-based emissions. It does not consider, for example, embedded emissions from manufacture and installation of the capacity. PV is estimated at having 39-49 gCO2eq/kWh of life cycle GHG emissions, whereas coal generation ranges from 730 to 1,370 gCO_2eq/kWh (Hsu et al. 2012; Whitaker et al. 2012). [12]NREL's System Advisor Model was used to model the performance of a standard-efficiency south-facing PV panel tilted at latitude for each site, and the solar resource of the most populous city for each country was used as an input. Local grid carbon intensity was obtained from IEA's CO2 Emissions from Fuel Combustion 2015 report (IEA 2015b).

TABLE 2. POTENTIAL AVOIDED EMISSIONS

UN Regions*	Estimated Electricity Production in 2013 (TWh/year)**	Average CO_2 Emissions from Electricity Production in 2013 (g/kWh)	Total CO_2 Emissions from Electricity Production (mmt/year)	5% Increase in Electricity Production (TWh/year)	Average PV Productivity (kWh/kW)†	PV Capacity that would generate 10% of a 5% increase in electricity generation (MW)	Avoided CO_2 emissions from fuel combustion (mmt/year)
Australia and New Zealand	292	703	205	14.6	1,415	1,033	1.03
Caribbean	82	532	44	4.1	1,503	272	0.22
Central America	346	467	162	17.3	1,436	1,204	0.81
Central Asia	200	477	95	10.0	1,415	705	0.48
Eastern Africa	75	231	17	3.7	1,559	240	0.09
Eastern Asia	7,326	675	4,945	366.3	1,345	27,236	24.72
Eastern Europe	1,697	470	798	84.9	905	9,372	3.99
Middle Africa	27	224	6	1.4	1,559	87	0.03
Northern America	4,939	445	2,198	247.0	1,299	19,012	10.99
Northern Europe	817	264	216	40.8	832	4,908	1.08
Nothern Africa	315	479	151	15.7	1,533	1,026	0.75
South America	1,125	234	263	56.3	1,382	4,071	1.32
South-Eastern Asia	793	583	462	39.6	1,217	3,257	2.31
Southern Africa	256	923	236	12.8	1,701	752	1.18
Southern Asia	1,647	714	1,176	82.4	1,529	5,388	5.88
Southern Europe	780	361	282	39.0	1,296	3,010	1.41
Western Africa	60	415	25	3.0	1,443	206	0.12
Western Asia	1,027	634	651	51.4	1,592	3,227	3.26
Western Europe	1,513	275	416	75.6	896	8,446	2.08
World‡	23,315	528	12,310	1,165.8	1,377	84,674	61.55

* Lists of what countries are within each UN Region can be found at UNstats.un.org under Methods and Classifications.
** Data for electricity production and carbon intensity obtained from the IEA's CO_2 Emissions from Fuel Combustion 2015 report. Aggregations of countries were distributed to their respective UN region by population weight.
† PV productivity calculated using SAM for a flat plate module tilted at latitude, using the closest solar resource data to the most populous city in each country within each region.
‡ Excluding Melanesia, Micronesia, and Polynesia. These regions have less than 0.01% of the world's emissions from electricity production.

the tens of thousands. Diesel is currently the dominant fuel source for these systems, although a growing effort to hybridize these systems with renewables is underway. Taking the carbon emissions from diesel fuel as 725 g/kWh, the estimated avoided emissions if 50% of the energy were to come from renewables instead of diesel would be 19.1 million metric tons of CO_2.[14]

Expanding on this notion, there is also a significant opportunity to deploy low carbon renewable-based DG in communities lacking access to energy services (1.2 billon people globally [IEA 2016]) to support both climate and development goals (presented in the last section).

[13]Additionally, the avoided emissions per kWh of PV is often less than the average carbon intensity of the local grid. For example, in a study of the Western Interconnection of the United States, a 33% energy penetration of wind and solar avoided 29%-34% of CO_2 emissions (Lew et al. 2013). The magnitude of the difference is caused by the fuel types that the renewable generation is displacing, and increased emission rates caused by increasing ramping as thermal generators change their output to follow the hour-to-hour variation in renewable generation. [14]725 g/kWh is the average implied carbon emissions from electricity generation from diesel fuel in Organisation for Economic Co-operation and Development (OECD) member countries between 2009 and 2013, as estimated in IEA's CO2 Emissions from Fuel Combustion (IEA 2015b). The value should be taken as illustrative, especially considering the differences in both generation efficiency and transmission losses between OECD member countries and small island nations.

Box 7 provides an example of one of the more than 40 off-grid DG systems in Alaska that are reducing the demand for diesel generation and supporting GHG emission mitigation with the deployment of renewable energy technologies and hybridized systems that significantly reduce the total amount of diesel consumed in a given year.

As described in this section, renewable-based DG can support emission reduction goals articulated in Nationally Determined Contributions and LEDS. Building on potential climate mitigation benefits, the next section explores DG's role in supporting climate resilience. In an example that bridges these two areas, Box 8 highlights DG efforts implemented by the Blue Lake Rancheria, Federally Recognized American Indian Tribe, to support integrated climate resilience and mitigation goals.

Box 7. Chaninik Wind Group

The Chaninik Wind Group Multi-Village Wind Heat Smart Grid Project is a joint project of Alaskan villages Kipnuk, Kongiganak, Kwigillingok, and Tuntutuliak that is designed to drastically reduce the amount of diesel that the villages use for electricity and heat. The four villages, in remote western Alaska, are separated from the grid and have historically created all electricity through diesel generators. Diesel fueled heaters or boilers supply heat for most homes and community building. The new minigrids integrate supplying electric service and electric based heating systems with a high renewable energy contribution power system using 95kW wind turbines. Smart control systems balance the grid by optimizing between wind generation, diesel power production, and thermal energy storage. The project has reduced power plant diesel use and residential heating costs by 30%. In Kwigillingok, the addition of batteries and associated control systems has allowed the diesel generator to be turned off for over 30% of the year (DOE 2014).

DISTRIBUTED GENERATION AND RESILIENCE

In addition to supporting energy access and related development goals and GHG emission reductions, renewable-based DG can also play an important role in supporting climate resilience. Across the globe, the impacts of climate change and extreme weather are anticipated to grow, with developing nations facing particularly high risk.

Lessons from disruptive events such as Hurricanes Joaquin and Sandy can be applied across the world to improve power system resilience. Importantly, a number of clean energy solutions can contribute to a country's energy reliability and resiliency goals. Linking mitigation and adaptation through renewable energy deployment can create a positive cycle to address existing resiliency needs while also reducing adaptation needs for the future through proactive development. Renewable DG systems—particularly when paired with energy storage as islanded micro- or minigrids—can spatially diversify the power supply, reduce fuel dependency, allow for back-up energy supplies, decrease central grid demand, and reduce T&D losses, all critical aspects to increasing climate resilience. Key DG-related actions to address climate resilience are highlighted below.

SPATIAL DIVERSIFICATION

The modular nature of renewable energy technologies, such as wind turbines and solar PV, allows greater spatial diversification of energy supplies than conventional power generation systems that deliver power from a concentrated point or central location. This increased spatial diversification reduces the vulnerability of the energy supply to damage from a single event and/or in a single critical location, which increases overall energy system resilience. Spatial diversification of renewable sources and microgrids can allow power system operators to better balance the overall electricity supply and demand within set geographic zones called balancing areas. Planned spatial diversification of DG systems over these balancing areas can reduce technical integration challenges and increase the operational flexibility through more efficient energy dispatching. It should be noted that possible distribution system upgrades should be considered as part of the planning process when considering renewable energy system diversification. Planned diversification also helps proactively harden the system against the effects of localized weather perturbations on DG system output. It should be noted that the value of spatial diversification is most realized in areas with robust, modern grid infrastructure that can fully utilize DG systems.

Spatial diversification of DG systems also supports the grid through the incorporation of modern power conversion technologies. For example, ancillary services such as voltage regulation and control can be achieved through the power conversion technologies—such as advanced inverters—associated with grid-connected DG systems.

DISTRIBUTED GENERATION TO BALANCE DEMAND

DG systems that are interconnected to the central grid can benefit from the advantages of larger grid supplies over a long period but also contribute local power to the larger grid system. DG can increase resiliency by decreasing demand on the central grid and allowing for greater flexibility in generation and fuel use. This can be accomplished in various ways.

First, island-capable microgrids can disconnect from the central grid during major climate events to allow energy to be diverted to critical loads. This allows utilities flexibility in restoring generation stations, responding to critical outages, and shutting down systems before a major event to prevent damage.

Second, during times of peak demand, island-capable microgrids can disconnect from the grid and use self-generated energy. This provides grid-side management of electrical supply and frees centrally generated energy for other loads. It also reduces operational costs of generating peak-demand electricity when prices are at a premium. In either case, the ability to divert energy away from the microgrid and toward other loads allows utilities greater flexibility in generation and distribution of power. When appropriately planned and managed, this can lead to reduced fuel consumption at the centralized generation plants, but it may result in increased fuel consumption within the microgrid.

Box 8. Blue Lake Rancheria

Blue Lake Rancheria, a Federally Recognized American Indian Tribe, has implemented multiple DG projects and constructed a microgrid to achieve climate, resiliency, and demand response goals. The renewable energy projects allow the tribe to reduce greenhouse emissions while also powering a microgrid that allows the local utility to balance demand. Additionally, the tribe's location outside of the California tsunami zone has made the tribe an evacuation center for nearby communities. With the new addition of an island-capable microgrid, the tribe's critical facilities can remain powered through major grid outages (Petersen 2015).

Figure 4. Entrance to Blue Lake Rancheria Tribe's microgrid project, which supports key climate and development goals.

Figure 5. Left: Ocho Rios green community in Jamaica supports increased electric reliability through distributed solar and wind and microgrids. Right: A microgrid storage shed with batteries and inverters.

Fossil fuels are conventional sources of energy and many countries are concerned with their availability and price volatility. The integration of renewable DG systems allows for reduced dependency on fossil fuels by utilizing local renewable resources. This reduced reliance on fossil fuels enables countries to become less economically dependent on these often imported fuels, puts their domestic renewable resources to productive use, and potentially reduces long-term costs associated with energy generation. Reducing dependence on fossil fuels also decreases GHG emissions both in power generation from conventional sources and the transport of those fuels to be combusted. Box 9 highlights DG efforts in Jamaica that have reduced dependence on imported fuels and increased electricity resilience through fuel source diversification.

Box 9. Distributed Generation in Jamaica

In Jamaica, the residential cost of electricity from 2012 through 2015 saw monthly fluctuations between approximately US$0.25/kWh and US$0.37kWh (Doris et al. 2015) due to changes in the cost of imported petroleum to generate electricity. Additionally, The Jamaican Public Service (JPS) electric utility has reported losses at greater than 25%. Of the reported losses, over half were due to theft (JPS 2013). Increased use of renewable DG systems could help reduce both electric price and losses through reduced dependence on imported fuel and the siting of generation near the electric loads served.

In the 2015 USAID Greening the Grid-sponsored Jamaica National Net-Billing Pilot Program Evaluation, interviews with JPS customers in Kingston and Ocho Rios revealed a specific interest in solar DG with battery backup as a means to increase electric resiliency through fuel source diversification (Doris et al. 2015).

In February 2016, JPS announced that 2015 had seen a 30% decrease in grid outages compared to previous years. JPS largely attributed this reduction to infrastructure upgrades, including a three-year effort to replace analogue meters with smart meters. These upgrades have been lauded by the solar industry as the new meters allow for a more streamlined DG interconnection process as opposed to needing to employ a system of meter upgrades during DG installation (Thompson 2016).

MICROGRID BACKUP POWER IN THE EVENT OF GRID FAILURE

Many developing countries face power quality and reliability issues as well as frequent outages. Fluctuations in power can create greater vulnerability due to loss of communication networks, damages to electrical equipment, and losses in economic revenue. When paired with energy storage technologies, DG systems can provide back-up power during grid outages. Interconnected systems can be designed to disconnect from the larger grid to provide power to local customers in the event of a grid outage or power fluctuations. This type of islanded system—made possible through appropriate policies and interconnection agreements with a utility provider[15]—utilizes islanding controls to disconnect from the grid and enable operation behind the meter or without pushing power to the larger grid. Islanded DG systems ensure consumers have access to power during long-term power outages that impact central grid systems more severely, as can occur after major natural disasters. As climate change impacts are anticipated to grow and developing nations are at a higher risk from the impacts of climate change, distributed systems are one solution to help those countries achieve greater resiliency in both their energy infrastructure but also in those sectors that need reliable energy services.

DG systems can also be designed with dedicated AC outlets for use during grid outages. These systems do not have associated power storage but instead allow consumers to utilize renewable energy systems—most often solar PV—to meet basic services such as charging phones or batteries during grid outages. Dedicated outlet systems work through the incorporation of advanced inverters into the DG system and, like islanded microgrids, they disconnect from the grid in the event of grid failure for protection of both the DG system and the grid. In 2014, Hurricane Iselle directly hit the Hawaiian island of Oahu causing multiple electrical outages. However, numerous electrical customers with rooftop solar PV systems were able to power their homes during daylight hours without having additional battery backup. These customers all had DG systems with dedicated AC outlets (Shimogawa 2014). Because battery storage is still cost-prohibitive in much of the world, these advanced inverters provide a lower cost option for increased electrical resiliency.

[15]For additional information on microgrid governance, please see the International Microgrid Assessment: Governance, Incentives, and Experience (IMAGINE) at http://www.osti.gov/scitech/servlets/purl/1210909/. This report outlines a system of 10 recommended steps, including the development of standards and processes for interconnection, rate design, and assessment of incentive polices to further microgrid deployment.

Non-renewable energy systems can also serve as generation sources in the event of grid failure. Many critical infrastructure sites rely on back up diesel or gas generators as sources of power. However, these systems are subject to the same fuel scarcity and price volatility as centralized systems. Analysis by NREL has shown that creating hybrid solar PV and diesel generation microgrids could more than double the length of time diesel fuel would last during a long-term grid outage (Hotchkiss 2015). Box 10 and Box 11 highlight critical efforts to provide back-up DG power during weather-related disasters and other emergency events.

Box 10. Sendai Microgrid

The Sendai microgrid is a demonstration project built in 2004 by the New Energy and Industrial Technology Development Organization. It utilizes a combination of gas and solar generation. In 2011, the Great East Japan Earthquake cut off electricity supplies across the region. The Sendai microgrid automatically islanded from the main grid within seconds of the outage. Customers with DC service from the microgrid did not experience an interruption in service. The AC service was restored within 24 hours—a full two days before the local grid became operable. The un-interrupted DC service and quick restoration of AC service is credited with saving the lives of hospital patients who were on ventilators at the time of the earthquake (Hirose et al. 2013).

POLICY, CODES, AND STANDARDS

Resilience benefits from DG systems can only be actualized if the DG systems themselves are designed to withstand disruptive events. For example, in areas prone to hurricanes, it is critical that solar PV systems are designed to handle high wind loads without risk of damage or dislocation from system mounts and ballasts. In these same areas, wind turbines should be designed with appropriate cut out, shut down, and survival wind speeds to prevent turbine failure and damage. Appropriate building and construction codes should be included in all DG system design. The goal is not to produce power during a disruptive event but rather to return to the original state as soon as possible after the event.

Electrical system codes and standards were originally written for utility-controlled, dispatchable, centralized generation, transmission, and distribution systems. DG systems, on the other hand, meet none of these criteria as power can flow to and from the grid, they are generally non-dispatchable, and by definition are distributed rather than centralized. Electrical system voltage and frequency can be impacted by any new interconnected system. While an individual system may not have significant impacts, the sum total of variable generation on the grid may pose new challenges to grid operators who are charged with keeping voltages and frequencies within specified limits. This is especially true for small, stand-alone electrical grids, such as those on small islands, where localized perturbations cannot be balanced across a larger grid.

Electrical codes for DG systems, though not specifically designed to increase resiliency, decrease system vulnerability by establishing protocols to maintain a reliable electric grid with minimal disruptions in service or variance of voltage and frequency.[16] Many small island grids experience greater variance in both voltage and frequency than larger national grids. These grid systems may see voltage and frequency variance that is outside of the tolerance levels of most DG inverters. When frequency or voltage swings exceed the software settings of the inverters, the DG systems will shut down or disconnect from the grid to avoid damage. This, in turn, can compound the voltage and/or frequency variance. Appropriate grid and equipment codes and standards can be used to address this type of issue on small island systems.

[16] See IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems. Its sub-components create standards and guidelines for conformance test procedures for interconnecting equipment, information exchange and control of distributed resources, design, operation, and integration of distributed resource island systems, and conducting distribution impact studies. UL 1741 the *Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources* sets requirements for inverters, converters, charge controllers, and interconnection system equipment for both off-grid and grid-connected DG systems. Both UL 1741 and IEEE 1547 are based on the presupposition that all electrical equipment is compliant with standard electrical codes such as NFPA 70, the National Electrical Code (NEC) in the United States.

Box 11. Hurricane Sandy

Princeton University implemented a number of actions to prepare for grid outages before Hurricane Sandy hit in 2012. In particular, the university isolated critical loads and ensured the thermal energy storage system was available to allow the power plant to 'black start' without grid connection. Princeton University was able to operate power in an islanded mode during Hurricane Sandy, serving as an emergency shelter for the local community, and avoiding $15 million in potentially lost research.

According to Greentech Media, over 200,000 gallons of fuel were needed per day to power the generators deployed to power critical infrastructure in the Northeast after Hurricane Sandy. Additionally, half of all gas stations in New York and New Jersey ran out of fuel within three days and prices increased to over $35/gallon (Lacey 2014) and fuel rationing policy remained in place for 15 days (Webley 2012). The cost of fuel, along with lack of infrastructure to move fuel to the hardest hit areas, rendered diesel fuel backup systems inadequate to power critical loads across the region (Lacey 2014).

As shown above, regulatory and policy environments can influence the impact of DG on electrical resilience. The presence of DG systems does not necessarily correlate with increased resilience. Appropriate policies, regulations, and codes must be coupled with DG to increase system resilience. For example, at the time of Hurricane Sandy, New Jersey had over 1,000 MW of installed solar capacity. However, only two solar PV systems provided power to homes or critical infrastructure in the days following the hurricane (Hotchkiss et al. 2013). At the time, a combination of interconnection policies and lack of dynamic controls or transfer switches prevented the islanding of systems. In other words, when the grid went down in the wake of the hurricane, all solar PV systems went offline. Without appropriate policies and codes, the installed solar capacity in New Jersey did little to aid resiliency. DG systems can be planned to maximize spatial diversification, utilize islanding capability, minimize transmission and distribution losses, and minimize possible negative impacts on the larger grid system. Nations wishing to increase resiliency through DG should adopt appropriate policy on interconnection and islanding to realize the full benefits of these energy generation systems.

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INTEGRATION OF DISTRIBUTED GENERATION INTO PLANNING AND POLICYMAKING PROCESSES TO SUPPORT LOW-EMISSION, CLIMATE-RESILIENT DEVELOPMENT

The previous sections provided a high-level view of DG's potential role in supporting key development and climate goals around the world. Table 3 brings information in the previous sections together to describe key actions and considerations to support development (via expanded energy access) and climate-focused DG deployment. It should be emphasized that data collection and analysis are two key elements in supporting robust DG planning. Two common DG analysis tools to support DG planning are highlighted in Box 12 and Box 13.

TABLE 3. KEY ACTIONS AND CONSIDERATIONS TO SUPPORT INTEGRATION OF DG WITH DEVELOPMENT AND CLIMATE-FOCUSED PLANNING AND POLICYMAKING

Establishing the Role of DG Deployment in Supporting Key Climate and Development Goals and Priorities
Assessing needs—Energy access, climate resilience, and mitigation needs and opportunities can be assessed at national and local levels to inform the role of DG in supporting key climate and development priorities. In some cases, these needs and opportunities may have already been assessed and can be drawn from existing climate strategies and electricity plans.
Analyzing future scenarios—High level scenarios analysis can also be conducted to understand possible future scenarios based on different criteria and considerations, including for example, expanded load growth, high and low cost of fossil fuels, and high climate change disruption that may be relevant to a climate and development-focused DG strategy.
Developing goals—Based on needs assessment, scenario analysis, and public stakeholder processes, priorities and goals can be established to articulate DG's role in supporting key climate and development (e.g., rural electrification) objectives. In some cases, these goals may have already been established and can be drawn from existing climate strategies and electricity plans.

Integrating Analytically Supported DG Options with LEDS and Broader Development Planning

Collecting data—Geospatially referenced energy needs, meteorological data, and economic data can be collected to support techno-economic analyses of different energy development opportunities. Currently isolated or islanded communities can be specifically noted with additional data collection on existing power generation undertaken.

Conducting analysis to compare options:

High-level techno-economic and climate impact analyses can be conducted to compare grid extension and DG electrification strategies for areas or communities not currently served by modern energy services.

For isolated communities, detailed techno-economic and climate impact analysis of technology options for DG-based electrification strategies at the local level can be conducted using local energy supply and demand data (using tools such as SAM[17], ReOPT[18], RETScreen[19] and HOMER[20]). SAM and HOMER are highlighted in Box 12 and Box 13.

For grid-connected industrial facilities or other high value loads, the economic impact of poor grid power quality and value of energy assurance can be assessed to inform potential development of advanced, centrally interconnected microgrids.

For other critical loads (e.g., hospitals, fuel stations, communications infrastructure, and government offices), develop awareness campaigns and/or offer incentives for developing microgrid infrastructure.

Assessing multiple impacts—To further evaluate technology options identified, multi-criteria impact assessment can be conducted to assess economic, social, and environmental impacts of technology options including both central station and DG energy options.

Identifying DG electrification zones—Based on analysis, high-value “DG electrification zones” can be identified for public and private investment, along with potential guidance and/or goals for technology options. For off-grid communities, this may include actual regions that will not be served in the near term by conventional grid extension. In the case of grid-connected areas, DG electrification zones may include areas where DG development can be incentivized under specific conditions and economic terms.

Integrating analysis-driven DG options with climate and development strategies—DG options prioritized based on analysis described above can be integrated with LEDS processes and broader development strategies to ensure consistency and mobilize climate finance for DG deployment.

[17] https://sam.nrel.gov/
[18] http://www.nrel.gov/tech_deployment/tools_reopt.html
[19] http://www.nrcan.gc.ca/energy/software-tools/7465
[20] http://www.homerenergy.com/

Supporting and Aligning with Relevant Electricity Planning Processes

Planning for grid-connected DG—Building on grid-connected DG options identified, first-order estimates of utility financial impacts under various compensation mechanisms can be conducted. These calculations can then inform estimates of expected grid-connected DG deployment and feed into centralized planning exercises. For remote areas that will not be served by isolated minigrid power systems, T&D expansion scenarios can be integrated with electricity planning exercises to inform T&D investments.

Planning for off-grid DG—Building on off-grid DG opportunities identified, regional electrification plans for unelectrified areas can be developed using various utility models, such as regional concession contracts. Effective regional electrification plans and utility models can support economies of scale for the implementation of minigrid power systems.

Designing Policies and Regulations

Developing locally appropriate compensation mechanisms and subsidies—Compensation mechanisms such as feed-in tariffs and net metering can be designed to support DG deployment. Subsidies can also be considered to support deployment and operation and maintenance of off-grid DG systems, while also aligning with needs of local communities and poor consumers. This can be especially crucial in areas where grid-connected electricity tariffs are highly subsidized.

Implementing standards and regulations—Robust standards and regulations can ensure safety, performance and quality of DG service. This includes equipment standards for generation equipment and (where relevant) inverters, and grid codes and interconnection standards that ensure DG systems are "good citizens of the grid."

Grid-Connected DG Considerations

To develop nationally appropriate qualitative and/or quantitative goals and inform program targets for grid-connected DG programs, first-order estimates of expected utility financial impacts under various scenarios of deployment and compensation structures can be utilized. These targets can provide the foundation for broader grid-connected DG policies and support mechanisms.

Isolated or Islanded DG Considerations

Building on the high-level climate and development goals described above, off-grid DG goals for specific communities and projects can be articulated in relation to level of service, renewable energy contribution, and targeted development and climate impacts.

To ensure that customers and communities receive the level of service defined within the goals described above, regulatory quality assurance frameworks and validation processes can be developed. For an example of specific steps that can be taken under a quality assurance framework process, see Box 4—Quality Assurance Framework for Minigrids. Further, specific rural electrification development programs/plans can be developed that articulate multiple pathways to ensure level of service to specific regions or communities.

Following project implementation, collecting and analyzing long-term system operational data can support communities, policymakers and project implementers in ensuring appropriate operation of power systems. These data can also inform off-grid DG policy, program, and project improvements over time.

Building on the high level climate and development goals described above, off-grid DG goals for specific communities and projects can be articulated in relation to level of service, renewable energy contribution, and targeted development and climate impacts.

Mobilizing Finance

Sharing information—Providing transparent information to investors on plans to extend the grid can support understanding of long term opportunities for DG (off-grid and grid-connected) to facilitate investment.

Supporting public-private partnerships—Pursuing public private partnerships can support communities in leveraging skills and expertise of the private sector. For example, ESCO service models, with formalized payment structures and appropriate legal mechanisms, can allow private sector entities to operate and maintain DG systems that may be funded or owned by governments. Standardizing and streamlining contractual processes, such as power purchase and interconnection agreements, is also critical for DG deployment.

Designing financial incentives and mechanisms—Based on unique local circumstances, designing community-specific incentives can support mobilization of finance. Common DG financial incentives include loan guarantees, grants, performance-based and tax incentives, and innovative financing mechanisms such as revolving loan funds and on-bill financing schemes, and buy-back programss, etc. In particular, it is often critical to reduce investment risks associated with off-grid power systems through implementation of defined reporting structures, application of direct financial support for microgrid development through grants, loans guarantees and other mechanisms, and development of pooled maintenance funds to address equipment replacement costs.

Building Capacity

Supporting policy design—Developing knowledge about regulations, policies, and utility structures for DG power systems is a critical to supporting DG programs. As one important example, capacity can be built to design locally appropriate tariffs for off-grid DG systems, where knowledge of DG, and renewable energy incentives more broadly, may be limited. Supporting stakeholder engagement is also an essential component of designing effective policies for both on-grid and off-grid DG programs. Policies and programs can also be implemented to improve both local technology development and design of sustainable business models, primarily for minigrid systems.

Increasing public awareness—Developing and implementing direct public outreach programs on DG technology options can build public awareness and support for DG technologies. Knowledge resources and publications, such as U.S. Department of Energy Small Wind Guidebook (http://en.openei.org/wiki/Small_Wind_Guidebook), can be instrumental in supporting public outreach efforts.

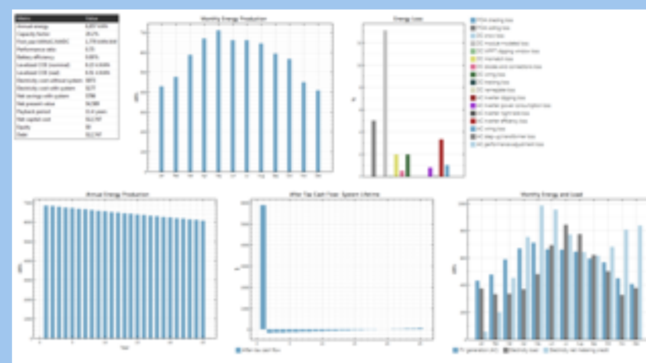
Training technicians—Implementing technician training and certification programs at the national and regional level can support design, installation, and operation and maintenance of DG systems, for both grid-connected and off-grid areas. Community-led efforts can also be supported by connecting communities with reliable DG developers.

Sharing knowledge on successes and challenges—Developing co-learning opportunities and programs can allow utilities and community leaders to share knowledge to address challenges and replicate successes related to central and off-grid use of DG technologies. One example of a co-learning program is the Utility Variable-Generation Integration Group, which provides a forum to share information and analyze DG utility applications. For more information, please visit http://uvig.org/newsroom/.

While the actions outlined above can provide a useful structure to support development and climate goals through DG deployment, there are other considerations related to incorporating DG into centralized electricity planning and policy development processes that should be addressed. Most importantly, individual consumers considering the installation of a DG system make decisions about when and how to invest their money for very different reasons than an electric utility, which has a narrow set of investment options and objectives and tends to follow least-cost decision-making patterns of meeting demand while maintaining highly reliable service. Further, it is currently common practice that policymakers only send signals to consumers to deploy DG, rather than create a requirement to deploy a certain technology, as can be the case for utilities.[21] Therefore, it is challenging to predict, and to create models to predict, levels of DG deployment and the pace of that deployment. This in turn impacts impacts the abilities of policymakers to set quantitative DG targets, particularly in the early stages of a DG program when the market is not well understood or developed. Once a market is better understood, particularly with respect to how DG deployment will respond to various investment signals, it may become more straightforward to formulate targets (along with the suite of strategies to achieve them).

Box 12. System Advisor Model (SAM)

SAM supports performance predictions and cost of energy estimates for power projects based on capital and operating costs and user-input system design parameters. The software includes the ability to model battery storage coupled with solar PV. At the distributed scale, users can model solar PV, solar thermal, and wind projects. For more information please visit https://sam.nrel.gov.



Building on this point, in nascent or early stage DG markets, there is often very little information on potential utility revenue impacts of DG deployment. While setting quantitative goals and then calibrating compensation mechanism levels and incentives for achieving those goals may be possible in theory, it may be politically unfeasible in practice. Therefore, in early stage DG markets, it may be most appropriate to set qualitative DG targets that can be followed by more concrete quantitative targets after DG markets are further established. As these markets grow and technology improves, it is anticipated that the global community will benefit from lessons learned and insights gained from these market and policy innovations.

As DG markets develop further around the world, there is interest in better representing DG technologies in demand forecasting, generation planning, and integrated energy sector scenario development. These processes go beyond least-cost electricity planning to assess electricity options in relation to climate, development, and other key criteria aligned with national and local goals. While integration of DG with these more comprehensive planning frameworks is still in an early stage, some processes currently consider DG as a net reduction to load. However, there is movement to better represent DG through expansion or development of new modeling approaches that better account for the potential impact of DG on a system by using intra-hour assessments of the role of various sources in reliably meeting load requirements (Siemens 2015). Improved representation of DG within these processes could provide policymakers and utilities with a more complete view of the electricity landscape and the rapidly evolving options available to achieve climate and development goals.

[21] Governments can promote deployment on their own buildings, or empower the electric utility itself to install distributed systems on the rooftops of consenting consumers (e.g., via a rooftop rental scheme).

Box 13. Hybrid Optimization of Multiple Energy Sources (HOMER)

HOMER supports on-grid and off-grid microgrid design optimization, incorporating renewable and traditional electricity sources, storage, and demand management. The tool has been applied in 193 countries to support economic, social, and environmental development goals. HOMER also offers several training resources and an online forum to share challenges and solutions. For more information, please visit http://www.homerenergy.com

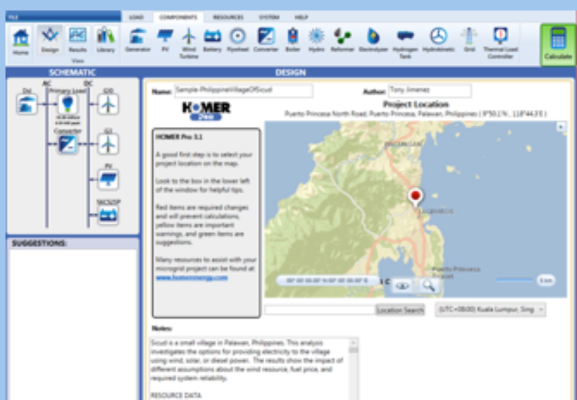


Photo Source: http://www.homerenergy.com/HOMER_pro.html

SUMMARY

Distributed generation, as part of a broader electricity provision portfolio, can play a critical role in supporting development and climate objectives articulated in LEDS, Nationally Determined Contributions , and the UN Sustainable Development Goals. This paper provides a high-level analysis of DG's potential to support economic and social development via energy access, GHG emission mitigation, and climate resilience. Further, drawing from international experience, key actions and considerations are highlighted to support integration of DG with development and climate-focused planning and policymaking processes.

Many challenges still exist in fully aligning DG with electricity planning processes that consider climate and development impacts. Notable challenges relate to setting appropriate DG targets in early stage markets and developing modeling approaches to account for electricity system, climate, and development impacts of DG deployment. To address these challenges, there is a need for international collaboration to develop improved methods to incorporate DG within electricity planning processes, especially in cases where plans will seek to integrate and advance climate or other development objectives.

As the DG market grows around the world, the technologies and market structures to support their deployment are evolving rapidly. The pace of this change creates opportunities for information sharing and insights on new and innovative approaches. However, as this market evolves and under this shifting electricity provision paradigm, it is clear that DG will play an increasingly important role in supporting a low emission, climate-resilient future.

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HOW EC-LEDS IS HELPING

- Improving the capacity of sectoral ministries to support Colombia's low carbon strategy by sponsoring dedicated staff.
- Building capacity of sectoral ministry staff to contribute inputs to and results from analyses that support Colombia's low carbon strategy.
- Strengthening cross-ministerial engagement by facilitating interaction and establishing regular communication channels.
- Strengthening alignment of goals and efforts among government ministries to support Colombia's low carbon strategy.
- Increasing awareness of opportunities to collaborate with international donors and non-governmental organizations on LEDS-related programs.

For questions about EC-LEDS

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